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*Original Research*

# Analyzing Ecological Functions in Coal Mining Cities Based on RS and GIS

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**Abstract**

Ecological problems have long been a hard issue in mining cities. This paper tried to present ecological functions in mining cities from two aspects: landscape ecology and ecological carrying capacity. The city of Qitaihe, one of the coal cities in Heilongjiang Province in northeastern China, was chosen as a typical study area. Remote sensing data from 1957, 1985, 2000, and 2015, and geographic information system (GIS) techniques were employed to obtain land use and cover information. Methods of landscape pattern indexes and a modified model of ecological carrying capacity which added social and economy index were used to study the spatial and temporal variation of the ecological condition. Results showed that the landscape pattern changed tremendously during the study period due to interference from human activity. The degree of aggregation, dominance, and fragmentation of mining land showed an increasing trend. On the other hand, the ecological carrying capacity per capita declined by 37.4% from 1985 to 2000. Except for the growth of population, the dim social and economic conditions had an impact on this decline too. In addition, spatial distribution of land types and ecological carrying capacity also had some correlation with the city's overall planning. The obtained results also provided suggestions that future research should encourage the combination between ecology and economy, as well as urban planning.

**Keywords**: Landscape ecology, ecological carrying capacity, remote sensing, urban planning, Qitaihe City

## Introduction

In recent years, coal mining cities, built and developed by mine exploitation, have been faced with severe challenges in China, including the declining economy and the worsening ecological environment, accompanied by rapid population growth and declining mineral resources. Generally, problems that hindered the development of these cities can be concluded to have been caused by human activity having surpassed ecological capacity [1-2]. Local governments from all levels have constituted many planning (Table 8) to guide the mining development and ecological environmental management. Thus, studying the variation and current status of the ecological environment from various aspects is vital for managers to comprehensively understand the mining expansion process and its effects on the ecological environment in mining cities.

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Landscaping has experienced persistent modifications at different levels of exploitation, which has led to permanent changes in resource degradation, environmental conditions, and so on [3-4]. Landscape ecology has emerged as an applied field for studying the past, current, and future of the landscape, including landscape pattern metrics and some analytical models [5]. These efforts have long been realized by computation, including remote sensing and geographic information systems (GIS). Recently, urban landscape ecology focused mainly on three aspects: 1) the influence of urbanization on ecological systems, such as the effect of urban heat island [6], environmental effect [7], water effect [8], ecological service effect [9], and so on; 2) using landscape pattern indexes to analyze different urban expansion types [10-11]; and 3) applied landscape ecology in ecological land use [12]. For resource-based cities, how to promote the sustainable development of the city remains an important topic, so in landscape study, multi-scale and multi-models were used to study the influence of resource exploitation on the ecosystem. However, in general, the previous study attached importance to quantitative research on landscape pattern change, and the application of landscape ecology in urban layout and design is rather limited. As Forman suggested, the successful synthesis of ecology and design may offer the greatest opportunity to curtail the degradation of our remaining resources by combining nature and culture within landscapes [13].

The ecological footprint (EF) model put forward by Wackernagel has emerged as the world's primary measurement of humanity's demands on nature [14] and is now widely used as an indicator for measuring environmental sustainability [15-16]. Various methods have been used to calculate the EF of different countries and regions [17-18]. Generally, statistical data are mainly used in the EF model. Due to the coarse scale and long time lag of the statistical data [19-20], accuracy of the EF model can sometimes be doubted. Furthermore, the model excludes economic and social meaning. So in this study, we try to modify the model with some social and economic indexes in hopes of more comprehensively evaluating the ecological carry capacity (ECC). At the same time, remote sensing data from different time periods as well as GIS are used to get more objective land use data.

This paper focused on four coal mining cities in Heilongjiang Province in northeastern China, taking the city of Qitaihe as a typical example to study its landscape pattern change as well as its ecological carrying capacity. Qitaihe was listed as the one of the transition pilot cities in China in 2009. In recent years, it faced continuously declining economy and severe ecological problems. The city's GDP dropped by 30.97% – from 30.81 billion in 2011 to 21.27 billion in 2015. At the same time, in 2015 the city's subsidence area reached 217.5 $km^2$, or 3.5% of the total; area of vegetation destruction was 0.9% [21]. So it was an important task for local managers to make new spatial planning policies to restore the damage and advance the economy. GIS and remote sensing were employed to generate land cover information and characterize statistics of landscape types for assessing landscape structure and ecological carrying capacity in a disturbance-dominant mining area. The main objectives of the paper were: a) to describe the spatial and temporal fluctuations of landscape patterns of the mining area, b) to discuss the spatial and temporal variations of ecological carrying capacity, c) to provide evidence and future direction of urban planning, and d) to promote the sustainability of the region.

## Material and Methods

### Study Area

As one of four famous cities in China, Qitaihe enjoys a good geological location: it is in the middle of the city agglomeration with Jixi to the south and Shuangyashan and Hegang to the north (Fig. 1); it is also in the belt of the northeastern economic zone, with easy access to Russia in the north, and about 400 km from the provincial capital, Harbin city; geographically it is the junction of the Wanda and Zhangguangcai ranges. Located between longitude 130°06′-131°58′E and latitude 45°16′-46°37′N, the city has a semi-humid continental climate.

Qitaihe is characterized by its rich coal reserves. The type and quality of the coal in the city are both remarkable, making the city one of the three rare coal fields that need protective mining in China and the largest coking coal production base in northeastern China. Large-scale mining exploitation started in 1958 and expanded rapidly. Over the years, mining activity has brought leaps to the economy, but also caused some ecological problems. In addition, the city is also featured by the world's largest artificial Korean pine forest. The expansion of mine exploitation destroyed the forest to some extent, resulting

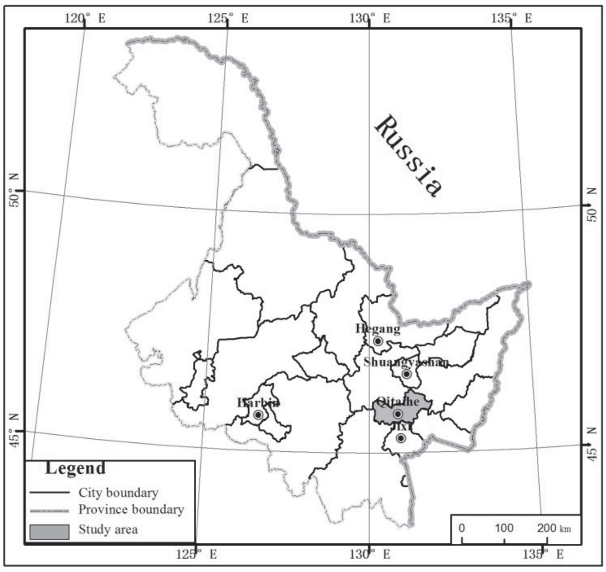


Fig. 1. Location of the study area.

Table 1. Data used in this study.

| Data | Path/row | Date of acquisition | Scale or resolution | Number |
|---|---|---|---|---|
| Topographic map | | 1979 | 1:50,000 | 1 |
| Land use map | | 2014 | 1:100,000 | 1 |
| Landsat5 | 150/28 | 1985-10-14 | 30 | 1 |
| Landsat5 | 150/28 | 2000-9-1 | 30 | 1 |
| Landsat8 | 150/28 | 2015-9-15 | 30 | 1 |

in a loss of biological diversity and growth of ecological vulnerability. Qitaihe has an area of 6,223 km$^2$, and administratively it is divided into three districts and one county, including Xinxing District, Taoshan District, Qiezihe District and Boli County.

## Data Source

The remote sensing data used in this paper were 1985 and 2000 Landsat TM images, and 2015 OLI images with 30 m spatial resolution. For geometry verification, the topographic map with 1:50,000 resolution for 1979 and land use map with 1:100,000 resolution for 2014 were used. Table 1 listed the main data in this paper.

## Visual Interpretation

Based on the national land use classification system and previous studies in this field [22-23], this paper divided the landscape into the classes noted in Table 2.

According to features of different bands, we used false-color composite images for image processing. For Landsat OLI 8 in 2015 we used bands 8, 5, and 3, and for Landsat TM 5 in 1985 and 2000 we used bands 7, 4, and 2. Then we conducted a geometry rectification fortopographic map of 1979 using Erdas 2014. Then this rectified map was used to check the Landsat 5 TM image of 1985. We selected more than 10 control points and controlled mean location error less than 1 pixel. Other images were processed in this way. Visual interpretation work was done by GIS 10.X based on image characteristics such as size, shape, tone, texture, site association, and pattern [24]. The minimum mapping patch was 6*6 pixels during the interpretation, and after that we conducted indoor validation work using the land use map of 2014. Finally, the overall accuracy of the interpretation was more than 90%.

Table 2. Land use/cover classification system in this study.

| Type | Description |
|---|---|
| Cropland | Dry farmland, irrigable land |
| Forest | Trees, shrubs, sparse vegetation, and other forested lands |
| Grassland | High coverage grassland, medium coverage grass land, low-coverage grass land |
| Water area | River, lake, reservoir or pond |
| Construction land | Urban area, rural residential area, other built-up area |
| Mining land | Open-pit area, overburden-dump area |
| Unused land | Sandy land, saline land, bare land, bare rock, other unused land, swamp |

## Landscape Pattern Indexes

Landscape pattern indexes can quantitatively describe and monitor the change of landscape spatial structure over time. The degree of fragmentation can reflect the temporal and spatial variation of patch size, number, area and coherence [25]. The selection of landscape indexes must take its ecological meaning into consideration. In many cases, the single index has certain limitations, while the accumulation of many indexes may be redundant and contradictory. Based on former studies [26-27], this paper selected total class area (CA), percentage of landscape (PLAND), landscape shape index (LSI), and largest patch index (LPI) to describe the whole landscape variation, and patch density (PD), mean patch size (MPS), edge density(ED), and patch cohesion index (COHESION) to focus on the fragmentation degree of mining land. These characteristics were described by the following equations:

$$LSI_i = L_i / 2\sqrt{\pi A_i} \quad (1)$$

$$LPI_i = \max_{j=1}^{n}(\mathrm{A}_{ij}) * 100 / \mathrm{A} \quad (2)$$

$$ED_i = L_i / A_i \quad (3)$$

$$COHESION_i = \left(1 - \frac{\sum_{j=1}^{n} P_{ij}}{\sum_{j=1}^{n} P_{ij\sqrt{A_{ij}}}}\right) * \left(1 - \frac{1}{\sqrt{A}}\right)^{-1} * 100 \quad (4)$$

…where $A_i$ denotes the area of mining landscape, A denotes the total area of the landscape, $A_{ij}$ denotes the area of patch j, and $P_{ij}$ denotes the diameter of patch j. Fragstats 4.2 is used to analyze these indexes. To compare different indexes, some of the indexes are made from some conversion: LPI'=LPI*10, PSCV'=PSCV/100.

### Ecological Footprint (EF) Model

EF is defined as a measurement of the human demand for land and water areas, and compares the human consumption of resources and absorption of waster with the earth's ecological capacity to regenerate [28]. EF transfers the unit of land area ($hm^2$) to global area units ($ghm^2$) as the amount of bio-productive space [29], so as to achieve the aggregation between different land use types and different regions. As an important part of EF, ecological carrying capacity (ECC) can reflect the total supply of world averaged productivity from all of the biologically productive land and water within a given year. The calculation of ECC is:

$$ECC = N * ecc \quad (5)$$

$$ecc = \sum_{i=1}^{n} A_i * EQ_i * Y_i \quad (6)$$

…where ECC denotes the total ecological carrying capacity of the area, N denotes total population, ecc denotes ecological carrying capacity per capita, $A_i$ denotes the area of land type i per capita, $EQ_i$ denotes the equilibrium factor, and $Y_i$ denotes the yield factor.

Obviously, the traditional model excludes social and economic factors. Here we improved the model by adding a new indicator that can reflect the social and economic development condition to some extent. The indicator can be calculated as:

$$F = A * B * C \quad (7)$$

…where A denotes the industrial structure index, equal to the proportion of tertiary industry in total GDP in the corresponding year; B denotes the human resource index, equal to the proportion of labor force in the total population; and C denotes the economy capacity index, equal to the GDP of the study year divided by the previous year. All of the data here are from the Qitaihe Statistical Yearbook. The EC model can be modified as follows:

$$ecc = (\sum_{i=1}^{n} A_i * \mathrm{EQ}_i * Y_i) * \mathrm{e}^F \quad (8)$$

The equilibrium factor ($EQ_i$) and yield factor ($Y_i$) are used because ecological productivity differs by country and land type. $EQ_i$ used in this paper came from the China Ecological Footprint Report 2012 [30]. The $EQ_i$ of the seven land types are as follows: cropland 2.39, forest 1.25, grassland 0.51, water area 0.41, construction land 2.39, mining land 2.39, and unused land 0. The $Y_i$ used in this paper came from the China yield factor in 2008 [31], which was as follows: cropland 1.7, forest 1.2, grassland

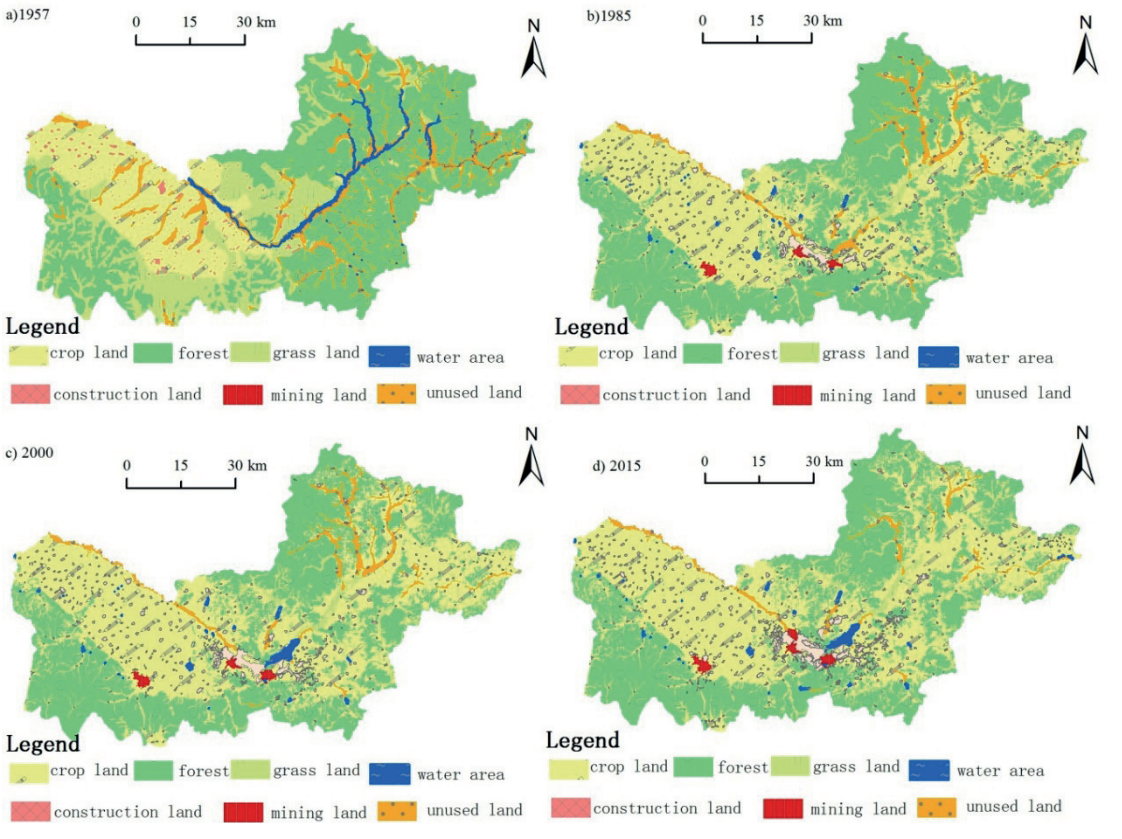


Fig. 2. Land use and cover change in the study area from 1957 to 2015.

0.8, water area 2.8, construction land 1.7, mining land 1.7, and unused land 0.

## Results and Discussion

### Dynamic Change of Landscape Pattern

#### *Change of the Whole Landscape*

Land use and cover change in the study area from 1957 to 2015 are shown in Fig. 2. During the study period, under the interference of human activity the areas of cultivated, construction, and mining land kept increasing, while the areas of grassland and unused land kept declining.

Fragstats 4.2 was employed to describe the dominant degree of landscape through landscape indexes CA and PLAND (Table 3). In 1957, 48.01% of the total area was covered with forest; 19.83% of the area was grass, and mining land could hardly been seen at that time. The mining activity started in 1958 deeply changed the landscape pattern. Area of cropland increased from 1,169.17 km$^2$ to 2,958.83 km$^2$, and became the dominant land type in the study area (2,938.75 km$^2$, 47.43% in 2000; 2,958.83 km$^2$, 47.76% in 2015). Area of construction land increased from 75.26 km$^2$ to 175.67 km$^2$, and area of mining land increased from 0.13 km$^2$ to 100.28 km$^2$. At the same time, forests kept declining, from 2,974.67 km$^2$ in 1957 to 2,552.57 km$^2$ in 2015. Likewise, unused land declined from 692.29 km$^2$ in 1957 to 135.68 km$^2$ in 2015. It was not hard to find that the annual change rate of mining land differed from the three time periods, which was the beginning (1957-85)>the end (2000-15)>the middle (1985-2000). That was because from 1957 to 1985, mining exploration expanded quickly, so the change rate was the highest, and from 2000 to 2015, coal industry entered its golden decade with a high development rate.

#### *Change of Mining Land*

We used LSI, LPI, and PSCV to describe the mining landscape change. LSI indicated the complexity of mining patch shape. LPI and PSCV reflected the size of mining patch and its stability. It was shown in Fig. 3 that from 1957 to 2015 (with the increase of CA and PLAND of mining land), LPI, LSI, and PSCV were all increasing, which showed that mining became more important in the whole landscape with its shape being more complex and its structure more stable.

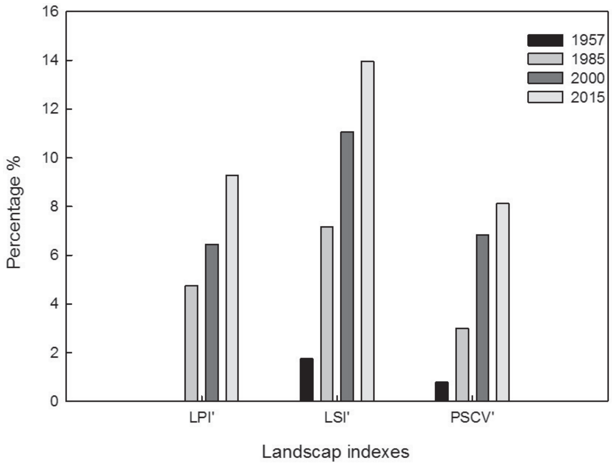


Fig. 3. Basic features of mining landscape between 1957 and 2015 in Qitaihe.

Fragmentation change included the spatial and temporal change of patch size, number, area, and cohesion. It was closely linked with human interference, and as the interference intensified, the fragmentation degree deepened. PD and MPS were basic fragmentation degrees, which reflected the fragmentation degree from quantity and area. ED was the perimeter of the landscape area, which reflected the boundary of patches and its complexity. COHESION could reflect the connection between patches. Table 4 showed that from 1957 to 2015 the PD kept increasing; MPS reached its highest in 1985, and then declined. ED experienced a process of increase-decline-increase, and reached its highest in 2015. As for COHESION, it increased from 1957 to 2000 and declined in 2015. In general, we found that the fragmentation degree of mining landscape was the highest in 2015, with

Table 3. Area and area percentage change of land type from 1957 to 1985.

| Type of landscape | 1957 | | 1985 | | 2000 | | 2015 | |
|---|---|---|---|---|---|---|---|---|
| | CA (km$^2$) | PLAND (%) | CA (km$^2$) | PLAND (%) | CA (km$^2$) | PLAND (%) | CA (km$^2$) | PLAND (%) |
| Cropland | 1,169.17 | 18.87 | 2,447.28 | 39.50 | 2,938.75 | 47.43 | 2,958.83 | 47.76 |
| Forest | 2,974.67 | 48.01 | 2,998.07 | 48.39 | 2,541.82 | 41.02 | 2,552.57 | 41.20 |
| Grassland | 1,228.96 | 19.83 | 305.36 | 4.93 | 240.53 | 3.88 | 236.40 | 3.81 |
| Water area | 55.51 | 0.90 | 10.74 | 0.17 | 33.74 | 0.54 | 36.41 | 0.59 |
| Construction land | 75.26 | 1.21 | 140.70 | 2.27 | 148.18 | 2.39 | 175.67 | 2.83 |
| Mining land | 0.13 | 0.00 | 42.38 | 0.68 | 62.18 | 1.00 | 100.28 | 1.62 |
| Unused land | 692.29 | 11.17 | 251.35 | 4.06 | 230.63 | 3.72 | 135.68 | 2.19 |

Table 4. Mining fragmentation degree in Qitaihe from 1957 to 2015.

| Fragmentation indexes of mining land | 1957 | 1985 | 2000 | 2015 |
|---|---|---|---|---|
| PD | 0.001 | 0.003 | 0.018 | 0.032 |
| MPS | 4.33 | 211.9 | 54.54 | 49.89 |
| ED | 0.005 | 0.303 | 0.004 | 0.904 |
| COHESION | 57.56 | 97.08 | 95.89 | 95.12 |

Table 5. Socio-economic development index of 1985, 2000, and 2015.

| Year | Industrial structure index (A) | Human resource index (B) | Economic capacity index (C) | Social-economic development index (eF) |
|---|---|---|---|---|
| 1985 | 0.20 | 0.19 | 1.12 | 1.04 |
| 2000 | 0.40 | 0.18 | 1.03 | 1.08 |
| 2015 | 0.47 | 0.15 | 0.99 | 1.07 |

more complexity and less connectivity, as well as stronger heterogeneity and discontinuity.

We used ArcGIS 10.x to draw the mining landscape change in the four different periods and found that the middle part of the city was less fragmented than other areas. The middle part was also where the urban center was located, which was Xinxing and Taoshan districts, which were also places where early mining exploration started. MPS remained highest among the entire period, and also proved that all the mining activities were concentrated in the middle part of the area. After 1985 a lot of new mining spots appeared in the eastern part of Qitaihe and increased quickly. This increasing trend became more obvious between 2000 and 2015, making the fragmentation degree in 2015 the highest. Thus, the intensified fragmentation degree should be sourced back to some small and irregular mining spots.

## Change of Ecological Carrying Capacity (ECC) from 1985 to 2015

This section discusses the change of ecological carrying capacity in the past 30 years. ECC was calculated by formula (5), and results showed that it kept increasing – from 1.59*$10^6$ ghm$^2$ in 1985 to 1.80 *$10^6$ ghm$^2$ in 2000, and to 1.83*$10^6$ ghm$^2$ in 2015. On the contrary, ECC kept declining from 1985 to 2015. From 1985 to 2000 it decreased from 2.43 ghm$^2$ to 2.24 ghm$^2$, decreased by 7.8%, and from 2000 to 2015 decreased from 2.24 ghm$^2$ to 1.52 ghm$^2$ and decreased by 32.1%. So the rapid growth of population made ECC drop. On the other hand, social and economic conditions affected ECC to some extent, too. Table 5 listed the social and economic development index (Formula 7). The index increased from 1985 to 2000, and then decreased from 2000 to 2015. Formula 8 showed that when $e^F$ was above 0, it had a positive effect on ECC. So the decline of the index made ECC drop more sharply and it decreased by 32% from 2000 to 2015. Table 5 also showed that economic capacity index kept decreasing, which had become a worrying subject in many coal cities in Heilongjiang Province.

For the variation of ECC between different land types, we drew Fig. 4, which shows that ECC differed greatly between these land types. Cropland, as the main ECC type on which human beings live, had the highest proportion. In 2000 the ECC of cropland reached 71% of the total. Forest was second to cropland, but showed a different trend than cropland. With the decrease of ECC of cropland from 2000 to 2015, the ECC of forest increased, which was linked with the "grain for green project" in the study area. The percentage of ECC of other land types remained relatively stable. Water area occupied a small percentage in the whole landscape, and the ECC was neglected here.

Based on the land use and cover map of 1985, 2000, and 2015 (Fig. 2), the transfer matrix of ECC was calculated to further depict the transfer of each land type (Tables 6-7). As shown in the tables, ECC of different land types transferred with different directions and trends. For cropland the main transfer happened in mining land, construction land, and forest. The gain of ECC of mining land mainly came from cropland, which occupied 92% of the total increase. The increase of construction land came from cropland too, representing 98.6% of the total increase. For forest, most of the output amount was cropland. ECC of water area increased from cropland too, representing 94% of the increased amount, which was mainly due to the building of Taoshan Dam in the city center. ECC of grassland remained stable in total. The productivity of unused land was rather low so it is not discussed here.

Generally, ECC showed a discrepancy before and after the transfer. From 1985 to 2000, ECC increased by 2,149.79 ghm$^2$, but the total land area remained

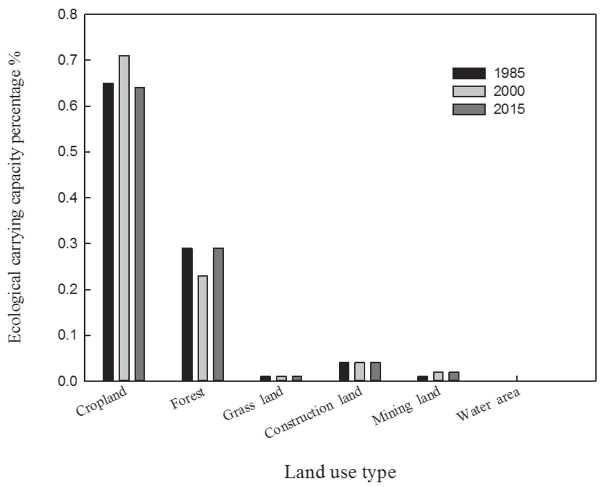


Fig. 4. Ecological carrying capacity of each land type in Qitaihe.

Table 6. Transfer matrix of ECC in Qitaihe from 1985 to 2000 ($ghm^2$).

| Land use type | Cropland | Forest | Grassland | Water area | Construction land | Mining land | Unused land |
|---|---|---|---|---|---|---|---|
| Cropland | 1,018,541.70 | 1,079.16 | 450.34 | 1,410.51 | 3,206.42 | 7,050.59 | 1,708.36 |
| Forest | 72,344.18 | 394,174.56 | 566.44 | 0 | 41.41 | 563.29 | 0 |
| Grassland | 2,417.34 | 528.10 | 10,038.49 | 0 | 0 | 0 | 0 |
| Water area | 52.11 | 0 | 0 | 1,220.84 | 0 | 0 | 0 |
| Construction land | 46.80 | 0 | 0 | 46.31 | 59,930.85 | 0 | 0 |
| Mining land | 0 | 0 | 0 | 107.64 | 0 | 17,830.34 | 0 |
| Unused land | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 7. Transfer matrix of ECC in Qitaihe from 2000 to 2015 ($ghm^2$).

| Land use type | Cropland | Forest | Grassland | Water area | Construction land | Mining land | Unused land |
|---|---|---|---|---|---|---|---|
| Cropland | 1,255,457.17 | 8,644.05 | 0 | 1,160.32 | 10,125.37 | 13,267.83 | 0 |
| Forest | 171.79 | 410,286.57 | 87.79 | 10.35 | 131.56 | 1,077.01 | 0 |
| Grassland | 152.06 | 5.24 | 10,405.17 | 0 | 13.95 | 55.13 | 0 |
| Water area | 15.57 | 0 | 67.17 | 4,096.40 | 0 | 0 | 0 |
| Construction land | 0 | 0 | 0 | 0 | 65,682.12 | 0 | 0 |
| Mining land | 0 | 0 | 0 | 0 | 0 | 27,422.33 | 0 |
| Unused land | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

unchanged, so the land use type change was the main factor that caused the 2,149.79 $ghm^2$ increase of ECC, among which the transfer of cropland, mining land, and construction land were the main driving force.

## Correlation With Urban Planning

In order to present the distribution of ECC of each land type, we drew the absolute value map of ECC based on a land use map. The spatial ECC map was based on each polygon and its corresponding equivalence factor and yield factor, which can reflect the variation of ECC due to different land use types (Fig. 5).

As shown in Fig. 5, the distribution of ECC was rather uneven. The middle was higher than the surroundings. Generally, ECC showed an increasing trend, and the eastern part increased more obviously. To know the distribution of ECC in different districts, we combined the spatial distribution map of ECC with urban planning.

Overall planning in Qitaihe (2012-30) specifies the direction of future development. The spatial development of the city is summarized as "two development axes and multi-centers" (Fig. 6). The multi-centers include one main urban center, two sub-centers, and five points represented by the circle with different sizes in Fig. 6. We can find that the ECC of the two axes are obviously

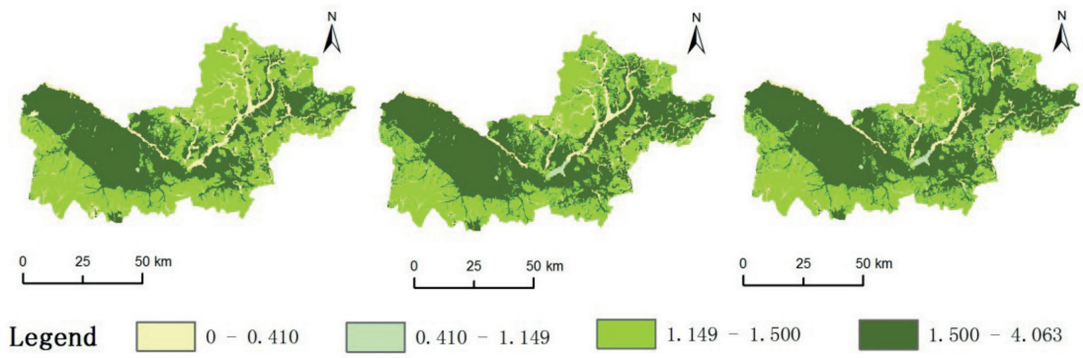


Fig. 5. Spatial distribution of ecological carrying capacity in Qitaihe.

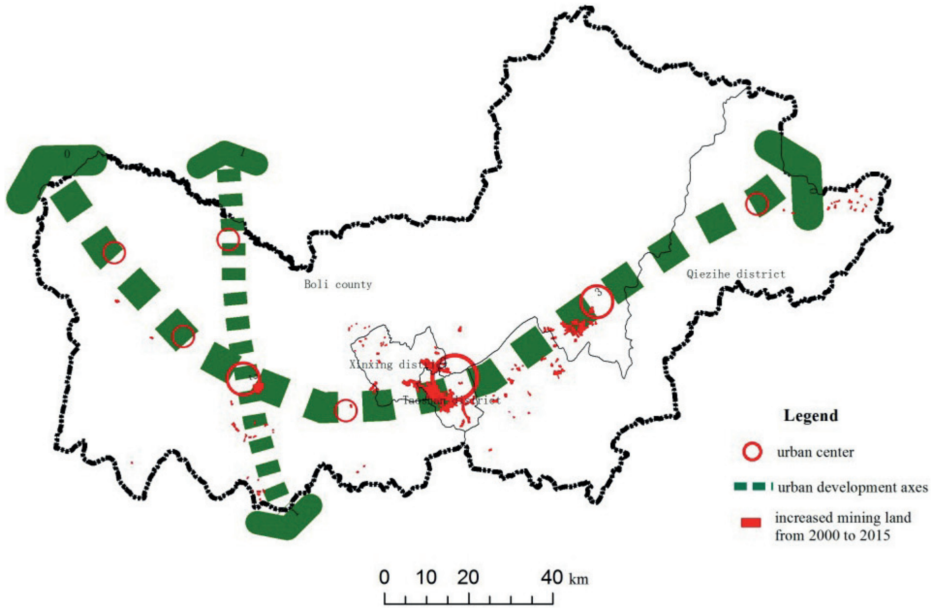


Fig. 6. Spatial development in the study area.

stronger than other places, which echoes urban planning. At the district level, ECC in Xinxing is the highest among all districts, because it is the place that most of the large deposits are located, and also the former city center. The ECC of Taoshan District is second to Xinxing. It is the current city center and is well developed. ECC in Qiezihe District is not evenly distributed, but the eastern part sees an obvious increase. Boli County is not well developed yet, so ECC in the county is high in the west due to the large amount of cropland, but relatively low in the south.

On the other hand, for a mining city it is of great importance to monitor the change of mining land, including the change in area and direction. From the analysis in 4.1, we can find that in 2015 the area of mining land increase rapidly, and fragmentation degree increased too. To present the spatial change of the mining land, we drew the increased mining land from 2000 to 2015 on the basis of the city map (Fig. 6). It is easy to find that most of the increased mining land from 2000 to 2015 are in the axes, mainly focusing on Xinxing and its eastern part; the rest of the increased part is distributed in the western and southern parts of Boli County. So we can say that the expansion of mining activity from 1985 to 2000 also echoes local planning.

## Discussion

Coordination between mining industry development, economic progress, and ecological protection remains a hard issue in resource-based cities. Generally, we think that in mining cities, when mining activities expand, some economic progress is achieved at the sacrifice of the environment, which implies that the two items “economic growth” and “environmentally friendly” are contradictory. But this is not true in Qitaihe. Although through the above analysis we can find that mining

Table 8. Relevant regulations and policies for mining development and ecological protection in coal cities in Heilongjiang Province.

| Relevant policies | Descriptions |
|---|---|
| Sustainable development planning of resource-based cities in China | As for sustainable development in Heilongjiang province, the four coal cities (Jixi, Shuangyashan, Hegang, and Qitaihe) should be taken as the key points. We should promote the relocation and renovation of old industrial zones, carry out the governance of industrial wasteland, and set up the special project of comprehensive treatment in the mining subsidence zone. |
| Planning of ecological environmental protection in Heilongjiang Province in the 13$^{th}$ Five-Year Plan | We should promote green, cycle, and low-carbon development in resource-based cities. In mining cities we should enhance the restoration and control of the mining geological environment, boost abandoned land reclamation and ecological restoration, and prohibit newly increased mining exploration within the red line area of ecological protection. |
| Ecological function zoning in Heilongjiang Province | The city of Qitaihe was listed into agriculture, forest, and mining ecological zones in Sanjiang Plain. Cropland and wildwood protection and mining reclamation were the zoning focal points. |

activity expanded at a rapid pace from 2000 to 2015, this does not bring economic progress, and a bad economy directly cause the fall of ecological carrying capacity per capital. What is worse is that environmental problems such as subsidence and vegetation destruction become serious. The rapid growth of population, irregular mining, and lack of environmental protection may be among the reasons that cause this embarrassing problem. Actually, governments at all levels have realized this and enacted some related policies. Here we list the main regulations and policies regarding mining developing environmental protection in coal cities in Heilongjiang Province in hopes of paving the way for future studies of coal mining cities in the province.

In addition, in the landscape ecology and ecological carrying capacity analysis, the authors have emphasized mining land change, because we consider mining activity to be a factor that influences the local landscape most. However, only from present data, the extent of the damage to ecological processes due to the expansion of mining activity is not well estimated. Future work should be done more on the correlation analysis between mining exploitation and ecological conditions.

## Conclusions

The analysis of landscape ecology in mining cities provides an example of the use of remote sensing and GIS to develop a database of mining cities covering a long time period. Our analysis showed that landscape pattern changed tremendously during the study period due to interference by human activity. As mining land became more important, it became more fragmented. The irregular exploitation of small mines is the main reason. So limiting small ones and regular large ones should be a future task in mining landscape treatment.

The application of remote sensing data and GIS also provides technical assurance to the visualization of spatial and temporal variation of ECC, and more importantly they make up the previous defects, which relied mostly on statistical data. In addition, this paper tries to take social and economic development into consideration, which provides a new perspective for studying ECC and EF. Results showed that ECC kept declining over 30 years. Social and economic development quickened the declining trend. Meanwhile, ECC of mining land and construction land mostly came from ECC of cropland, and the area of cropland per capita kept decreasing during 30 years, so local managers should enact more policies to protect cropland and regulate the expansion of construction land and mining land in order to achieve sustainable development.

Finally, the study of landscape ecology and ECC prove that there are some correlations between ecology and urban planning. The obtained results also provide suggestions that future research should encourage the combination between ecology and economy, as well as urban planning, i.e., how ecology can guide urban planning in the long run in order to achieve sustainable development in resource-based regions.

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